

# Kinematics of the Spine During Sit-to-Stand Movement Using Motion Analysis Systems: A Systematic Review of Literature

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**Context:** Clinical evaluation of the spine is commonplace in musculoskeletal therapies, such as physiotherapy, physical medicine/rehabilitation, osteopathic, and chiropractic clinics. Sit-to-stand (STS) is one of the most mechanically demanding daily activities and crucial to independence. Difficulty or inability to perform STS is common in individuals with a variety of motor disabilities, such as low back pain (LBP). **Objective:** The purpose of this systematic review was to evaluate available evidence in literature to determine 2-dimensional and 3-dimensional kinematics of the spine during STS in patients with LBP and healthy young adult participants using motion analysis systems (electromagnetic and marker based). **Methods:** Electronic databases (PubMed/MEDLINE [National Library of Medicine], Scopus, ScienceDirect, and Google Scholar) were searched between January 2002 and February 2017. Additionally, the reference lists of the articles that met the inclusion criteria were also searched. Prospective studies published in peer-reviewed journals, with full text available in English, investigating the kinematics of the spine during STS in healthy subjects (mean age between 18 and 50 y) or in patients with LBP using motion analysis systems, were included. Sixteen studies fulfilled the eligibility criteria. All information relating to methodology and kinematic modeling of the spine segments along with the outcome measures was extracted from the studies identified for synthesis. **Results:** The results indicated that the kinematics of the spine are greatly changed in patients with LBP. In order to develop a better understanding of spine kinematics, studies recommended that the trunk should be analyzed as a multisegment. It has been shown that there is no difference between the kinematics of patients with LBP and healthy population when the spine is analyzed as a single segment. Furthermore, between-gender differences are present during STS movement. **Conclusion:** This review provided a valuable summary of the research to date examining the kinematics of the spine during STS.

**Keywords:** low back pain, functional activity, biomechanical phenomena, vertebral column

Sit-to-stand (STS) movement and its reverse, which are considered fundamental prerequisites for daily activities and functional independence, are repeated many times throughout the day.<sup>1,2</sup> Hughes et al<sup>3</sup> reported that STS is the most frequently performed functional activity in daily life. This maneuver is quite demanding from a neuromuscular perspective and is often affected by pathology and age.<sup>1,4-8</sup> STS consists of transferring the center of mass from a low position centered within a base of support to a high position over a shallow base of support.<sup>9</sup> In addition, STS movement requires around 60% of total sagittal-plane lumbar mobility per day.<sup>10,11</sup> It has been shown that people who have difficulty rising to a standing position have a greater likelihood of falling during ambulation<sup>3,12</sup> and need help with daily activities.<sup>13,14</sup> Inability to stand up has been linked to death in elderly people.<sup>15</sup> As a result, studying STS is encouraged by the fact that this maneuver is frequently described as painful by patients with chronic low back pain (CLBP) and is often addressed in rehabilitation programs.<sup>16</sup>

Normal spinal mobility is required for optimal performance of daily activities, and it has been reported that the impairment of

spinal mobility can result in various forms of functional disabilities,<sup>17</sup> which may have serious adverse effects on quality of life.<sup>1</sup> Patients with low back pain (LBP) have been shown to have some limitations in spinal motion that compromises their function. Therefore, the ability to reliably measure and evaluate lumbar spine motion is essential in elucidating the pathophysiologies of various musculoskeletal disorders, such as LBP.<sup>17</sup> The anatomy and function of the lumbar spine is complex and, therefore, requires a measurement technique that can record 3-dimensional (3-D) movements. Radiological imaging, including X-ray, fluoroscopy, and 3-D magnetic resonance imaging, are precise and accurate techniques that can evaluate intersegmental movement of spinal vertebrae.<sup>18,19</sup> However, these invasive methods could be harmful to patients.<sup>18</sup> Although electromagnetic tracking systems are a better alternative and would be a suitable technique for assessing functional activities (eg, gait, STS) in a clinical setting, the quantitative analysis of functional activities using optical motion analysis systems is well established, and has been used in clinical contexts for several decades in order to help diagnose, plan treatment, and assess treatment outcomes.<sup>18</sup>

Electromagnetic motion analysis and optical 3-D motion analysis systems are used for measuring range of motion (ROM) of multiple joints simultaneously. Both systems utilize markers for taking measurements, and it has been shown that they are highly accurate.<sup>20</sup> The electromagnetic motion analysis system (eg, Fas-Trak) is a noninvasive electromagnetic measuring instrument that tracks the positions of sensors relative to a source in 3 dimensions.<sup>21</sup> The optical 3-D motion analysis system (marker-based system) uses spherical retroreflective markers that can be identified by the

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cameras. The system outputs 3-D coordinates of detected markers usually at 100 to 120 frames per second.<sup>22</sup> Although high accuracy and the ability of multiple simultaneous ROM measurements are the main advantages of optical 3-D motion analysis systems, some disadvantages should be considered. High cost and potential influence of soft tissue artifact are the main disadvantages of marker-based systems.<sup>23</sup> The placement of markers on the skin overlying the spinous processes of the spinal column provides a noninvasive approach to measure dynamic movement of the spine during daily activities. It is also important to note that the difficulty in locating relevant anatomical landmarks to effectively define axial rotation in the transverse plane limits the analysis of lumbar spine kinematics to the frontal and sagittal planes using this approach for measuring functional tasks.<sup>18,24</sup> Nevertheless, Shum et al<sup>1</sup> reported that the magnitude of movements out of the sagittal plane during STS, and its reverse, are very small and can be neglected.

Although there are several noninvasive approaches reported within the literature, and the review of all these technologies are beyond the scope of this article, motion analysis systems are generally accepted to be the “gold standard” for STS, gait, and movement analysis.<sup>18</sup> Therefore, the purpose of this systematic review is to critically investigate published literature to assess the kinematics of the spine during STS task in patients with LBP and healthy young adult participants using motion analysis systems (electromagnetic and marker based). It is hoped that this systematic review will be helpful in further understanding the kinematics of the spine during STS.

## Methods

### Scope and Boundaries

This review intended to examine the methodological considerations for 2-dimensional and 3-D analysis of spinal movements

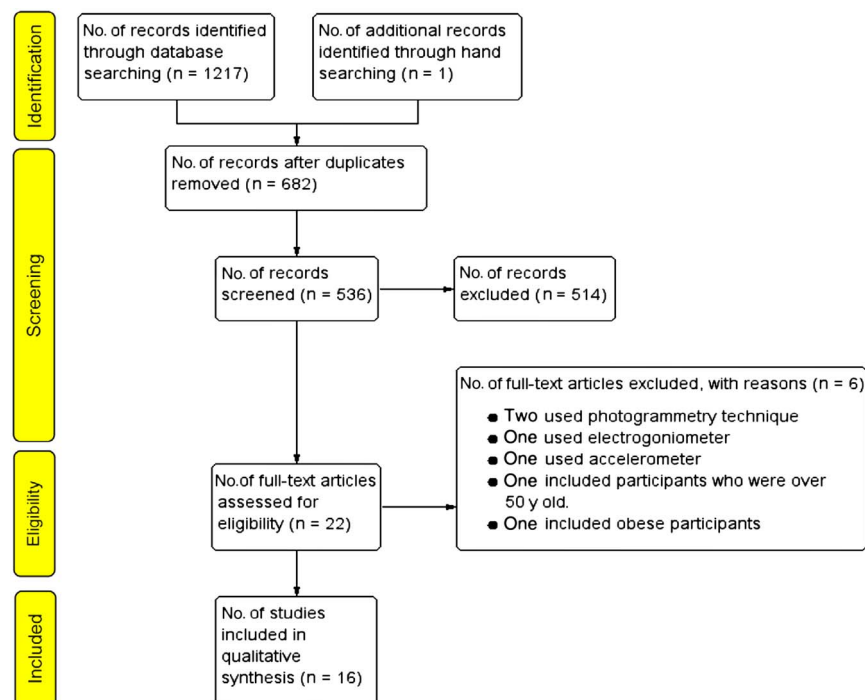
using motion analysis systems. Areas for review included study and participant characteristics, motion analysis system, marker/sensor design and placement, kinematic model description, data collection procedures, and outcome measures (ie, ROM, velocity, coordination, etc). This review did not critically analyze the mathematical procedures and algorithms used for maker detection.

### Search Strategy

The methods adopted for this review were compliant with the recommended Preferred Reporting Items for Systematic Review and Meta-Analysis checklist guidelines for systematic reviews. Moreover, the Preferred Reporting Items for Systematic Review and Meta-Analysis flow diagram was used to describe the number of primary studies that were included and excluded in each stage of the selection process (Figure 1). A single reviewer (M.R.P.) searched in electronic databases: PubMed/MEDLINE (National Library of Medicine), Scopus, ScienceDirect, and Google Scholar were searched, corresponding to the period from January 2002 to February 2017 (15 y). This period of time was selected for searching because before this period, most of STS studies used other instruments rather than optoelectronic motion analysis systems or electromagnetic sensors, such as light-emitting diodes,<sup>25</sup> simple video camera,<sup>26</sup> electrogoniometers,<sup>27</sup> and so forth. Details of the PubMed database search syntax were as follows:

“sit-to-stand” OR “sit to stand” OR “chair\* rise\*” OR “chair-rise” OR “chair\* stand\*” OR “stand\* up”) AND (“kinematic\*” OR “biomechanic\*”) AND (“spin\*” OR “trunk” OR “torso\*” OR “back”) AND 2002/01/01:2017/02/31[dp].

The syntax of this review was a combination of medical subject headings terms and free text words. The Boolean operators AND and OR were used, alongside phrase searching. Wildcards



**Figure 1** — Preferred Reporting Items for Systematic Review and Meta-Analysis flowchart of the study.

and truncations were also used to enable the search to retrieve all possible variations of a specific root word. To optimize the strategy for each of the other databases, appropriate changes were made in the basic search strategy. Moreover, a hand search through a list of references of included studies was conducted to identify other eligible studies.

## Inclusion Criteria

At the completion of the search, all references were transferred into EndNote, and duplicates were removed. Two reviewers (M.R.P. and R.B.) screened titles and abstracts of all primary articles that meet the search strategy in order to determine studies eligible for inclusion. If insufficient information was available in the title and abstract of an article, a full-text evaluation was undertaken. Then, the same 2 reviewers independently evaluated the full text of potentially relevant nonduplicated articles. Conflicts were resolved by discussion to reach consensus. In addition, it was planned that major discrepancies unable to be resolved by the reviewers would be taken to a third party (I.E.T.) for resolution. The following parameters were used to include the articles: Participants, Interventions/Diagnoses, Comparisons, and Outcomes criteria:

- (1) Study design: Observational (case-control and cross-sectional) studies published in peer-reviewed journals with full text available in English; results obtained from theses/dissertations, conference proceedings, abstracts, and websites were excluded. In addition, studies were excluded if they investigated the effects of assisted devices or any other intervention.
- (2) Participants and diagnoses: Studies in which participants were either healthy adults (mean age between 18 and 50 y) without functional limitations or patients with LBP. Other pathologies including spinal cord injury, Parkinson's disease, stroke survivors, multiple sclerosis, arthroplasty, amputation, and so forth, were excluded.
- (3) Comparisons: Studies in which the kinematics of patients with LBP were compared with healthy control participants. Studies in which only healthy participants (without a control group) were recruited, were also included for this review.
- (4) Outcomes: Studies in which one or more of the following outcomes were assessed: ROM in the cardinal planes, inter-segmental motions, velocity, and spine coordination.
- (5) Studies in which STS was assessed using a motion analysis system (electromagnetic or marker-based or inertial sensors) with no restrictions on methodology procedures (ie, rising speed, chair/stool height, sitting position).

## Methodological Quality Assessment

The methodological quality of the included studies was assessed using a modified quality assessment tool developed around the major research aims.<sup>28,29</sup> The quality assessment criteria included 13 appraisal questions and were specifically designed for assessing methodological procedures related to kinematic modeling and the reproducibility of a marker set configuration.<sup>28</sup> Two items (10 and 15) were added to the original checklist,<sup>29</sup> and 1 item (5) was modified. Item 5 was modified to "Is the spine (cervical and/or thoracic and/or lumbar) segment clearly stated?" Item 10 was added as "Were movement tasks clearly defined?"<sup>29</sup> In addition, item 15 was added as "Were conclusions drawn from the study clearly stated?"<sup>29</sup> (Table 1). Each item was scored as follows:

**Table 1 Assessment of Research Quality<sup>a</sup>**

1	Are the research objectives or aims clearly stated?
2	Is the study clearly described?
3	Are appropriate subject information and anthropometric details provided?
4	Are the marker/sensors locations accurately described?
5	Is the spine (cervical and/or thoracic and/or lumbar) segment clearly stated?
6	Is the reference position used to define anatomical frames reported?
7	Is the motion analysis equipment and set-up clearly described?
8	Are the segment coordinate systems clearly defined?
9	Are the model properties clearly defined for all joints (e.g. degrees of freedom)?
10	Were movement tasks clearly defined?
11	Are the methods used to describe the axes and order of rotations clearly described or referenced appropriately?
12	Are appropriate variability/reliability/repeatability procedures documented and reported?
13	Are the main outcomes of the study stated?
14	Are the limitations of the study clearly described?
15	Were conclusions drawn from the study clearly stated?

Note: Adapted from Bishop et al.<sup>28</sup>

<sup>a</sup>Items were scored as follows: 2 = yes; 1 = limited detail; 0 = no.

2 = yes, 1 = limited detail, and 0 = no. An article was deemed high quality if the total score was  $\geq 24/30$  (cutoff point = 80%).<sup>18,28,29</sup>

The 2 reviewers (M.R.P. and R.B.) independently assessed the quality of all included studies. The agreement between the 2 reviewers was calculated using Cohen's coefficient kappa (kappa: 0–.29 = weak agreement, .30–.59 = moderate agreement, .60–.89 = good agreement, and .90–1 = optimal agreement).<sup>30</sup> The results demonstrated that good agreement was present between the 2 reviewers (Cohen's kappa  $\pm$  SE was .71  $\pm$  .24).

## Risk of Bias Assessment

The risk of bias was analyzed for all individual studies using a checklist developed by the Grading of Recommendations Assessment, Development and Evaluation working group.<sup>31</sup> The risk of bias was classified as "high" or "low" or "unclear" if there was an insufficient description in the original reports.<sup>32</sup> One reviewer (M.R.P.) evaluated the risk of bias of each included study using the Grading of Recommendations Assessment, Development and Evaluation checklist for observational studies.

## Data Extraction and Analysis

To carry out descriptive analyses, data were independently extracted by the 2 reviewers (M.R.P. and R.B.) from the identified studies. The extracted data included the description of study characteristics (first author's name, year of publication, country in which the study was performed, and size of the sample); the description of study participants (number, gender, mean age, body mass index, and status of health); the description and characteristics of the motion analysis system used, alongside markers/sensors, measurement frequency, test procedures, kinematic outcome measures; and the conclusion.

Meta-analysis was not performed because the included studies were heterogeneous and methodologically different (procedures

and instrumentation). Therefore, this review focused only on description and qualitative synthesis of the identified studies.

Results

Identification of Studies

A total of 1218 studies were identified through the electronic database searches (Figure 1). After exclusion of duplicates and review of titles and abstracts, 22 studies were considered eligible for inclusion in our review. One study included participants who were more than 50 years old,<sup>33</sup> 2 studies used accelerometer or electrogoniometer,<sup>34,35</sup> and 2 studies utilized photogrammetry techniques.<sup>36,37</sup> Furthermore, 1 study recruited obese participants.<sup>38</sup> A hand search of references provided in the included studies identified 1 additional article.<sup>39</sup> Thus, a total of 16 studies were included in this systematic review.<sup>1,24,39–52</sup>

Quality Assessment

A summary of the quality assessment of the reviewed articles is presented in Figure 2A. Using an approach proposed by Bishop et al,<sup>28</sup> information required to sufficiently answer questions 6, 8, and 14 was not consistently provided in the articles included for review, and this was represented by a median score of ≤1 (Figure 2B). From the 16 articles reviewed, 10 articles were deemed to be high quality (Figure 2A).<sup>1,24,39,40,43,46–50</sup>

Risk of Bias in Included Studies

Following the assessment of risk of bias, the results indicated that 4 studies failed to develop appropriate eligibility criteria.<sup>41,45,51,52</sup> One study reported unclear information about the eligibility criteria as it only mentioned that healthy participants were included if they had no history of major musculoskeletal issues.<sup>43</sup> All included studies that compared patients with LBP with healthy participants did not match known prognostic factors between patients with LBP and their controls.<sup>1,42,46–48,50,51</sup> Incomplete or absent reporting of some outcomes was detected in 1 study.<sup>51</sup> Shafizadeh<sup>51</sup> did not provide sufficient information about the differences of coordination

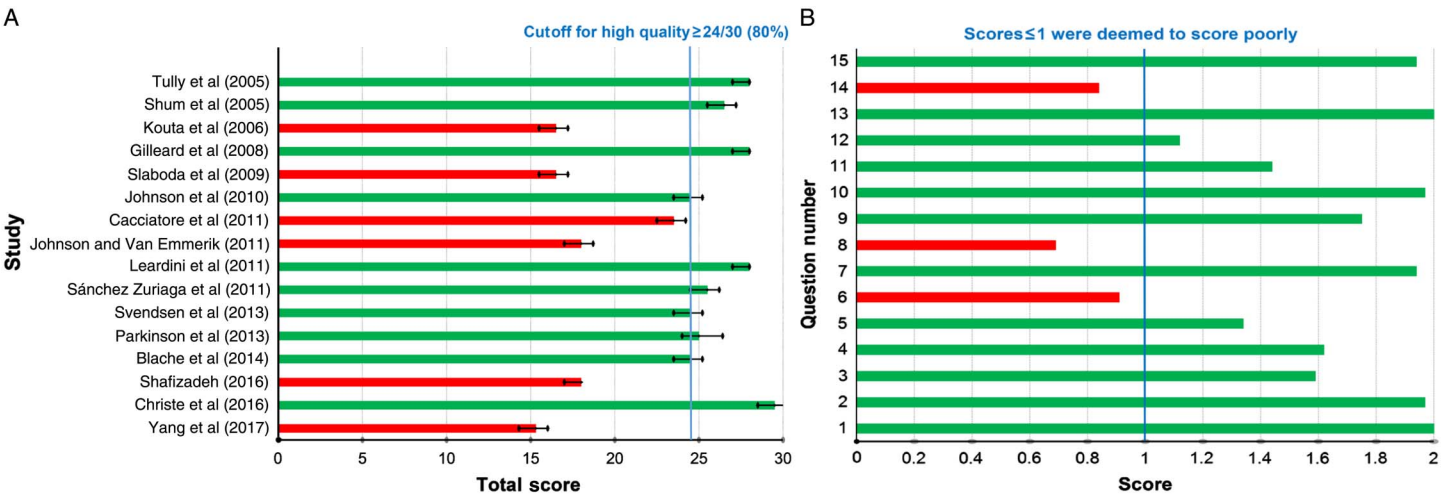
values between patients with LBP and healthy participants during the second half of stand-to-sit movement. Finally, no study indicated participants’ attrition (loss to follow-up). Figure 3 summarizes the risk of bias of the included studies.

Overview of Participant Characteristics

Table 2 provides a summary of the total number of participants recruited, along with their health status, gender, and age. The majority of studies included participants without a history of LBP. Both participants with and without LBP were included in 5 studies.<sup>1,46,48,50,51</sup> In most of the included studies, LBP was defined as a pain on the lumbar region for a period of 0 to 12 months without sciatica and neurologic deficits.<sup>46,48,50</sup> Moreover, Shum et al<sup>1</sup> included subacute LBP (7 d to 12 wk) participants with and without a positive straight leg raising test. Four studies did not provide information on gender,<sup>1,24,42,46</sup> whereas 3 studies examined only male participants<sup>41,49,52</sup> and 1 study included only female participants.<sup>39</sup> Parkinson et al<sup>47</sup> assessed gender separately to show between-gender differences during STS task. The mean age of included studies population at baseline ranged from 20.1 to 46.2 years. None of the included studies clearly justified their sample size.

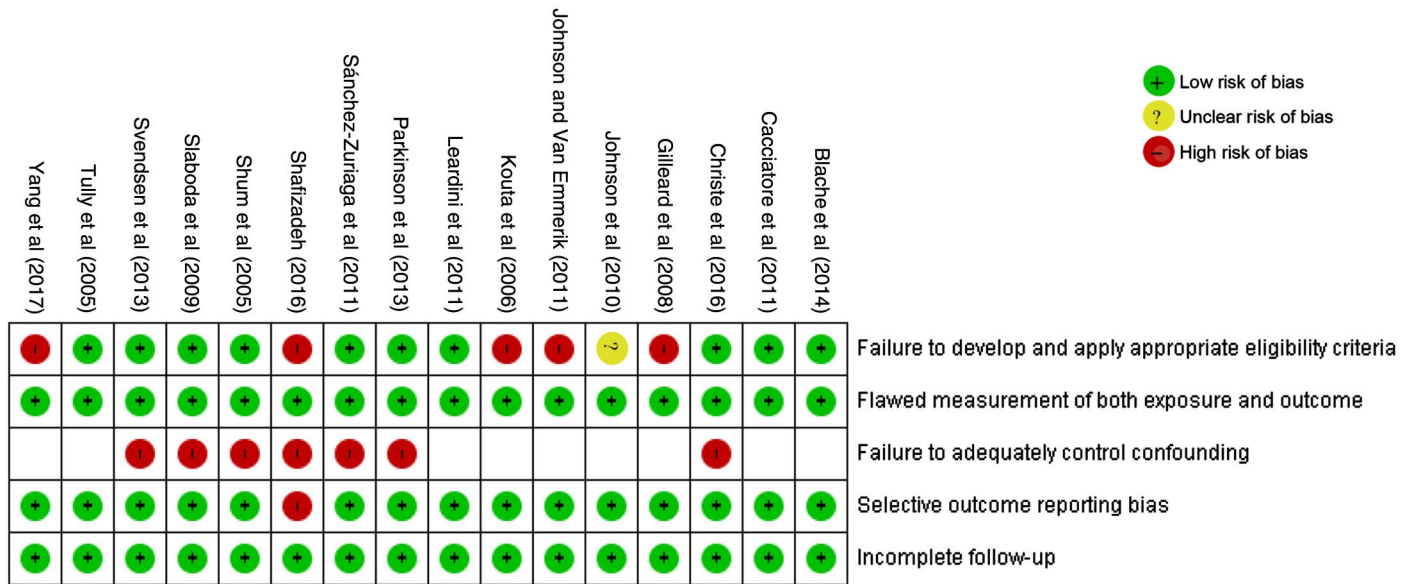
Methodology Considerations and Outcome Measures

The literature reports a wide range of models for spine segments. Two studies considered the whole-trunk kinematics during STS,<sup>41,48</sup> whereas the others evaluated the different parts of the spine during STS and its reverse. In Johnson and Van Emmerik’s<sup>45</sup> study, no precise information has been available regarding the spinal modeling. Moreover, Slaboda et al<sup>42</sup> and Kouta et al<sup>41</sup> reported only head–arm–trunk and head segments kinematics in participants without LBP and did not provide further details about the kinematic model used for the assessment of STS. The majority of the included studies evaluated the kinematics of the spine in the sagittal plane, whereas some studies investigated the kinematics in the frontal and transverse planes.<sup>39,46,48</sup> Christe et al<sup>50</sup> revealed that sagittal-plane angle of the lumbar and thoracic regions was



**Figure 2** — Quality assessment results. (A) The median score for each article as judged by the 2 reviewers. The light gray (red in online) rows are indicative of those studies deemed not high quality (ie, a mean score < 24/30). (B) The median score for each question in the appraisal tool. The light gray (red in online) rows are indicative of those questions that were poorly addressed (ie, a median score ≤ 1).





**Figure 3** — Risk of bias summary for kinematic parameters. Because 9 studies<sup>24,39–41,43–45,49,52</sup> included only 1 group of participants, therefore, it was not possible to assess the limitation of controlling confounding factors in these studies (empty boxes).

significantly limited in nonspecific CLBP participants compared with healthy adults. Likewise, Shum et al<sup>1</sup> reported limited lumbar spine sagittal-plane ROM in subacute LBP patients with and without a positive straight leg raising. However, Svendsen et al<sup>48</sup> found no significant differences in overall trunk angle between patients with LBP and healthy participants. Two studies mentioned that the trunk as a single segment could not adequately represent the spine kinematics.<sup>47,50</sup> Parkinson et al<sup>47</sup> reported that healthy males and females represented different lumbar spine sagittal-plane ROM during STS. Furthermore, Christe et al<sup>50</sup> indicated that the kinematics of the spine are different in the upper and lower parts of the lumbar and thoracic in participants with nonspecific CLBP and without LBP. They showed that patients with nonspecific CLBP performed STS with less spinal movement in the lumbar, but also in the thoracic regions.<sup>50</sup> It has been demonstrated that the trunk segment displaces in the frontal and transverse planes during STS in patients with LBP<sup>48</sup> and healthy participants.<sup>39,48</sup> Large inter-segmental motion over the 3 anatomical planes has been reported by Leardini et al<sup>24</sup> The effects of seat height and 3 different foot positions on L5–S1 kinematics were investigated in Blache et al<sup>49</sup> study. They reported that low-height seat and neutral foot position resulted in greater L5–S1 ROM.<sup>49</sup> Shafizadeh<sup>51</sup> evaluated decomposition index values for the lumbar–hip joint pair as indicators of interjoint coordination. He concluded that patients with LBP had significantly higher decomposition indices relative to healthy participants during STS and stand-to-sit movements.<sup>51</sup>

Angular velocity of the spine was also assessed in 5 studies.<sup>1,41,42,45,50,51</sup> Limited angular velocities in subacute LBP and patients with nonspecific CLBP have been reported by Shum et al<sup>1</sup> and Christe et al<sup>50</sup> studies, respectively. In addition, 1 study showed that head-on-trunk extension during STS decreased peak head velocity in the anteroposterior and vertical directions.<sup>45</sup> Slaboda et al<sup>42</sup> indicated that environment can alter the velocities of the trunk and head.

Accurate marker/sensor positions were provided in the majority of studies.<sup>1,24,39–41,43,44,46–48,50</sup> Measurement frequencies used

within the included studies ranged from 25 to 200 Hz, and 4 studies used MATLAB software (The MathWorks Inc, Natick, MA) for data processing.<sup>24,43,45,50</sup> The majority of the included studies described the procedure in detail.<sup>1,24,39–47,49–52</sup> Stool’s height, arm position, feet position, and rising speed were the most common items mentioned in the studies. Participants in all studies were asked to perform STS at a preferred speed. Number of STS trials ranged between 3 and 15 trials. However, 4 studies reported no information on the number of trials.<sup>24,40,41,47</sup> Finally, reliability analyses were appropriately documented and reported in 9 studies.<sup>1,24,39,40,46–50</sup>

Discussion

Assessment of spinal mobility is critical for estimating disability, evaluating outcomes, and guiding nonsurgical treatment approaches.<sup>53,54</sup> Motion analysis systems can provide high accurate information of the spine kinematics during various tasks, and it has been reported that optical motion analysis systems are the golden standard in motion capture and analysis.<sup>55</sup> In addition, motion analysis systems are noninvasive, allow for the repetition of the examination more times within a short period of time, and provide quantitative and 3-D data. The results of this review indicated that patients with LBP have limited sagittal-plane angle and smaller angular velocity compared with healthy participants. Decreased ROM may be due to pain, muscle spasm, muscles coactivation, or stiffness. Sung<sup>56</sup> mentioned that coactivation of the paraspinal muscles is used to immobilize the lumbar spine as a protective strategy to avoid provocation of pain. In addition, increased spinal stiffness could alter movement patterns of patients with LBP in a harmful way and possibly increase sensitization of spinal and peripheral structures, which could adversely contribute to the chronicity of pain.<sup>50,57,58</sup> In Shum et al’s<sup>1</sup> study, it was found that patients with subacute LBP had a significant reduction in velocity in both the lumbar spine and hip joints, and took a longer time to complete STS and its reverse movements. They mentioned that patients with LBP probably decrease trunk velocities and

Table 2 Studies Are Listed in Time-Ordered Manner From Most Recent to Oldest by Year of Publication

Characteristics of motion analysis system and markers/ Participants' characteristics position		Measurement frequency, Hz	Analysis software	Processing	Task and test procedure	Number of trials	Spinal segment modeling	Outcome measures	Conclusion
Study	Participants' characteristics								
Yang et al <sup>52</sup> (2017), Japan	Eleven healthy male participants; age: 24.5 (2.2) y, height: 1.73 (0.03) m, and body mass: 60.1 (2.4) kg	100	SIMM (Musculographics Inc, Santa Rosa, CA)	Second-order low-pass Butterworth filter at 5 Hz	STS; Participants were told to cross the arms in front of their chest to avoid using the arms. Additionally, they were asked to locate their feet 80° from the horizontal direction at the initial state of the experiment. The chair height was adjusted to the height of the participant's lower leg. The participants finished the motion without moving their feet in all the trials. Recording time for each trial was 10 s.	Fifteen trials for 2 strategies	NR	Lumbar spine ROM	Lumbar spine had larger ROM when using stabilization strategy (please see "Discussion" section for further explanation)
Christe et al <sup>50</sup> (2016), Switzerland <sup>a</sup>	Ten patients with CNLBP (5 males and 5 females; age: 38.2 [6.7] y and BMI: 21.9 [1.7] kg/m <sup>2</sup> ) and 11 healthy participants (6 males and 5 females; age: 36.7 [5.4] y and BMI: 22.9 [3.8] kg/m <sup>2</sup> )	120	MATLAB (R2013b)	NR	Cited Parkinson et al <sup>47</sup>	3	T1–T6: upper thoracic segment, T6–L1: lower thoracic segment, L1–L3: upper lumbar segment, and L3–L5: lower lumbar segment	Flexion and extension ROM and angular velocity at the lower lumbar, and upper thoracic lower, and upper thoracic healthy participants	Limited sagittal-plane angle and smaller angular velocity in patients with CLBP compared with healthy participants

(continued)

Table 2 (continued)

Study	Participants' characteristics	Characteristics of motion analysis system and markers' position	Measurement frequency, Hz	Analysis software	Processing	Task and test procedure	Number of trials	Spinal segment modeling	Outcome measures	Conclusion
Shafizadeh <sup>51</sup> (2016), United Kingdom	Fifteen patients with LBP (7 males and 8 females; age: 46.17 [8.28] y and BMI: unknown) and 15 age-matched asymptomatic healthy people (7 males and 8 females; age: 45.14 [5.18] y and BMI: unknown)	An 8-camera motion analysis system (SIMI Motion, Unterschleissheim, Germany); markers the S2, Rv/Lt ASIS, Rv/Lt thigh wands and markers were placed nearly 15 cm above the patella.	NR	NR	NR	STS and its reverse; Participants stood in front of adjustable chair (30–40 cm height) with neither armrest nor backrest. The height of the chair was adjusted so that the knee angle in the sitting position was 90° regardless of the participant's height. They were asked to perform STS at a preferred speed without using their hands and after 2–3 s they sat on the chair.	3	NR	Angular velocities of the lumbar spine and hip, decomposition indices relative to healthy group in whole STS, whole stand-to-sit, the first half of STS, and the first half of stand-to-sit	LBP people had significantly higher decomposition indices relative to healthy group in whole STS, whole stand-to-sit, the first half of STS, and the first half of stand-to-sit
Blache et al <sup>49</sup> (2014), France <sup>a</sup>	Fourteen healthy male volunteers; age: 26.6 (3.1) y, height: 1.76 (0.06) m, and body mass: 70.1 (8.0) kg	Ueye, (IDS UI-2220SE-M-GL; IDS Imaging Development Systems GmbH, Obersulm, Germany); 9 reflective markers were placed over Rt fifth MTP, LM, LFE, GT, ASIS, PSIS, T12, and C7.	100	NR	Fourth-order low-pass Butterworth filter with cutoff frequency of 10 Hz	STS; Participants with bare feet were instructed to stand up from a backless and armless chair at a self-selected speed, and the arms were folded across the chest. Three foot positions and 3 seat heights were tested: foot neutral and 2 foot back positions (–7.5 and –15 cm) and seat neutral, seat low, and seat high.	3	Lumbar spine was defined as a segment between C7–T12 and L5–S1 and GT.	L5–S1 ROM in the sagittal plane	Seat with low height and neutral foot position resulted in greater L5–S1 ROM

(continued)

Table 2 (continued)

Study	Participants' characteristics	Characteristics of motion analysis system and markers/sensors' position	Measurement frequency, Hz	Analysis software		Processing	Task and test procedure	Number of trials	Spinal segment modeling	Outcome measures	Conclusion
				Analysis software	Analysis software						
Parkinson et al <sup>47</sup> (2013), Australia <sup>a</sup>	Twenty-nine healthy participants (16 males and 13 females); age: 31 (13) y and BMI: 23.4 (3.0) kg/m <sup>2</sup>	3Space Fastrak (Polhemus Navigation Science Division, Kaiser Aerospace, VT); 3 sensors were placed over the spinous processes of T12, L3, and S2.	25	LabVIEW (version 6.1, National Instruments, TX)	NR	NR	STS; A stool was adjusted to a height that allowed each participant's thighs to be horizontal and the legs vertical, the feet were positioned shoulder width apart with arms relaxed, hanging next to the thighs. Participants were asked to stand up at their natural speed.	NR	T12–L3: upper lumbar segment, L3–S2: lower lumbar segment, and T12–S2: lumbar segment	Peak flexion, extension, and total ROM of the upper, lower, and combined lumbar spine kinematics, and were assessed in both genders	The lumbar spine as a single segment did not adequately represents lumbar spine kinematics, and there were gender differences.
Svendsen et al <sup>48</sup> (2013), Denmark <sup>a</sup>	Twelve patients with LBP (9 males and 3 females; age: 38.6 [9.8] y and BMI: 25.1 [3.2] kg/m <sup>2</sup> ) and 12 healthy participants (9 males and 3 females; age: 37.5 [9.7] y and BMI: 23.6 (2.1) kg/m <sup>2</sup> )	Qualisys motion capture system (Oqus system, Qualisys AB, Sweden); 35 reflective markers were placed over the first and fifth metatarsal, calcaneus, GT, LFE, ASIS, PSIS, acromion, L5, and 2 clusters on the tibia and femur.	200	QTM software (Qualisys Track Manager, Qualisys AB, Sweden)	NR	3–6	Stand-to-sit; Participants were requested to sit on a chair from standing and then return to the standing position.	3–6	AC–L5: trunk segment	Trunk motion in the sagittal and frontal planes	No significant differences were found in overall trunk angle between patients with LBP and healthy participants.

(continued)



Table 2 (continued)

Study	Characteristics of motion analysis system and markers/sensors' position		Measurement frequency, Hz		Processing	Task and test procedure	Number of trials	Spinal segment modeling	Outcome measures	Conclusion
	Participants' characteristics	analysis system and markers/sensors' position	Hz	Analysis software						
Sánchez-Zuriaga et al <sup>46</sup> (2011), Spain <sup>a</sup>	39 patients with LBP and 16 healthy participants (gender: unknown); age: 42 (11) y and BMI: 24.95 (3.5) kg/m <sup>2</sup>	Kinescan/IBV (Instituto de Biomecánica de Valencia, Spain); 12 reflective markers were placed over C7 (3 markers), the spinous processes of T12, L3, L5, sacrum, Lt iliac crest, femoral midline, LFE, and fibular midline (2 markers).	50	NR	NR	STS; A stool was adjusted to a height that allowed each participant's knee to be 90° flexed. The arms crossed over the chest. Then, participants were asked to perform STS with their own preferred speed.	5	Lumbar motion: angle formed by the intersection of the line between T12 and L3 markers and the line between L5 and sacrum, thoracic angle: intersection of the line between C7, inferior and a marker placed in the middle point between Rt C7 and Lt C7 with x-axis, and thoracic rotation: intersection of the line between Lt C7 and Rt C7 with y-axis	Reliability of lumbar and thoracic motion in the sagittal plane and thoracic motion in the transverse plane	Good to excellent reliability of this method was reported for spinal motion during STS with ICC values of $\geq .78$ .
Leardini et al <sup>24</sup> (2011), Italy <sup>a</sup>	Ten healthy participants (gender: unknown); age: 24.7 (0.8) y and BMI: 21.1 (1.7) kg/m <sup>2</sup>	Vicon motion capture system; 14 reflective markers were placed over Rt and Lt ASIS, Rt and Lt PSIS, Lt PX, Rt, and Lt AC, MAI, and the spinous processes of C7, T2, L1, L3, and L5	100	Vicon standard software and MATLAB	NR	STS and its reverse; A chair was adjusted to a height that allowed each participant's knee and hip to be 90° flexed, and the tibia was perpendicular to the floor. The arms crossed over the abdomen. They instructed to perform STS and its reverse at a self-selected speed.	NR	Spatial matching of II, PX, MAI, and T2: thorax segment and C7, T2, L1, L3, and L5: spine segment	Reliability and High ROM in all 3 planes	High intraobserver reliability and large intersegmental motions were reported over the 3 anatomical planes.

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Table 2 (continued)

Study	Characteristics of motion analysis system and markers/sensors' position		Measurement frequency, Hz		Processing	Task and test procedure	Number of trials	Spinal segment modeling	Outcome measures	Conclusion
	Participants' characteristics	Qualisys motion capture system; NR	100	MATLAB						
Johnson and Van Emmerik <sup>45</sup> (2011), United States	Twenty-four healthy participants (11 males and 13 females); age: 26.5 (4) y, height: 1.75 (0.1) m, and body mass: 72 (12) kg	Qualisys motion capture system; NR	100	MATLAB	Fourth-order low-pass Butterworth filter with cutoff frequency of 5 Hz	STS with different head orientations; Participants started sitting on stool adjusted to 100% knee height, with knees flexed to 85°, GT 4 cm posterior to the anterior edge of the stool, bare feet at a self-selected width, and the arms hanging at their sides. Participants performed STS with each of 4 different head orientations in random order: extended, flexed, forward, and neutral.	Four trials for each head orientation	NR	Peak trunk-in-space forward flexion angle, movement duration, and peak head velocity in the AP and vertical directions	Head-on-trunk extension decreased movement velocities, movement duration, and trunk flexion compared with flexed and neutral head-orientations.
Cacciatore et al <sup>44</sup> (2011), United States	Fifteen Alexander Technique teachers (4 males and 11 females); age: 42.7 (9.1) y, height: 1.69 (0.08) m, and body mass: 74.5 (11.3) kg	Falcon; markers were placed bilaterally on the lateral orbital margin, tragus of the ear, PSIS, GT, LFE, 3 cm proximal to the ankle joint along the fibula, lateral posterior calcaneus, and the first metatarsal, the spinal processes of C7, T4, T7, T10, L1, L4, and the midpoint of sacral crest	60	NR	Low-pass filter STS; 6 Hz	Participants sat on an adjustable height backless chair (105% of each participant's lateral knee epicondyle to floor). Initial foot position was adjusted, so the knee angle was 85°. Participants were instructed to stand up as smoothly as possible, without using momentum and at a self-selected speed.	5	Angle from C7 to sacrum relative to vertical: trunk-tilt; angle between C7, ear, and orbit markers: neck angle; summation of T4, T7, and T10 joint angles: thoracic angle; and summation of L1 and L4 joint angles: lumbar angle	Sagittal plane angles	Reduced spinal bending was occurred during STS in Alexander Technique teachers.

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Table 2 (continued)

Study	Characteristics of motion analysis system and markers/ sensors' position		Measurement frequency, Hz	Analysis software	Processing	Task and test procedure	Number of trials	Spinal segment modeling	Outcome measures	Conclusion
	Participants' characteristics	Qualisys motion capture system; 57 reflective markers were placed according to each participant's anthropometric measurements (17 (0.07) m, and body mass: 72.5 kg for calibration only)								
Johnson et al <sup>43</sup> (2010), United States <sup>a</sup>	Thirty-two healthy participants (15 males and 17 females); age: 27 (4.5) y, height: 1.72 (0.07) m, and body mass: 72.5 kg (7.5) kg	Qualisys motion capture system; 57 reflective markers were placed according to each participant's anthropometric measurements (17 (0.07) m, and body mass: 72.5 kg for calibration only)	100	MATLAB	Fourth-order low-pass Butterworth filter with cutoff frequency of 3 Hz	STS and its reverse; Participants were seated on a stool adjusted to 100% knee height (head of fibula) with GT 4 cm from the front edge of the stool. Participants' knees were flexed to 85°. Participants were instructed to perform STS at a self-selected pace while their arms hanging at their sides. Then, they were asked to sit on the stool for 6 s.	5	Cervical spine, upper thoracic spine (T1–T6), midthoracic spine (T7–T12), and lumbar spine Pelvis	Torso sagittal ROM	Greater ROM of torso joints during STS compared with sitting; greater lumbar/pelvis joint compared with the other torso joints; no gender lumbar STS differences.
Slaboda et al <sup>42</sup> (2009), United States	Ten healthy adult participants (gender: unknown); age: ranged from 21–49 y and BMI: unknown	Motion analysis infrared Hawk system (Santa Rosa, CA); NR	120	NR	NR	STS; Participants were seated on an adjustable stool with the ankles, knees, and hips at 90° of flexion. The feet were positioned with toes forward and parallel to one another, and the arms were at their sides. Then, they were instructed to perform STS in a virtual environment that rotated in the pitch and roll directions.	11	Head	Angular velocities of the head with respect to the trunk, and trunk with respect to the environment	Reduced head and trunk angular velocity were occurred after immersion in the moving visual environment; and there was time-dependent effect of vision on STS kinematics in adults.

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Table 2 (continued)

Study	Participants' characteristics	Characteristics of motion analysis system and markers/sensors' position	Measurement frequency, Hz	Analysis software	Processing	Task and test procedure	Number of trials	Spinal segment modeling	Outcome measures	Conclusion
Gilleard et al <sup>39</sup> (2008), Australia <sup>a</sup>	Twelve healthy female participants; age: 28.9 (4.1) y, height: 165.4 (4.9) cm, and body mass: 63.8 (8.0) kg	Expert VisionTM Motion Analysis System (Eva HiRes 5.00, Motion Analysis Corporation, CA); reflective markers were placed over the forehead, Rt/Lt ear, T4, T8, angles of Rt/Lt eighth ribs, Rt/Lt ASISs, Rt/Lt PSISs, sacrum, subtrochanter, LA, MA, mid thigh, tibial tubercle, LK, MK, first metatarsal base, and fifth metatarsal base	60	Kintrak software (KinTrak version 5.7, Motion Analysis Corporation, Santa Rosa, CA) PSIS - Rt/Lt ASIS - sacrum frequency of 6 Hz	Fourth-order zero-phase shift Butterworth filter with cutoff frequency of 6 Hz	STS; A height adjustable chair (seat height was set to 110% of fibular head to floor distance in standing) was used. The participants rose to stand at their preferred speed, while watching a standing eye level target. They chose initial foot position, which was maintained throughout. STS started with arms by the side; however, arms were free to move.	3	T4-T8 angles of Rt/Lt eighth rib; thoracic segment, Rt/Lt PSIS - Rt/Lt ASIS - sacrum; pelvis segment	Angular displacement in the frontal and transverse planes and transverse and moments were observed in trunk segments during STS.	Frontal and transverse plane displacements and moments were observed in trunk segments during STS.
Kouta et al <sup>41</sup> (2006), Japan	Nine healthy young men; age: 21.8 (2.5) y, height: 170.3 (4.9) cm, and body mass: 65.1 (6.8) kg	Vicon motion capture system; 10 reflective markers were attached to the both AC, GT, knee joints, LM, and the fifth metatarsal heads	120	Vicon workstation (version 4.6, Oxford Metrics, UK) and Microsoft Excel (version 2002, Microsoft Corporation, Redmond, WA)	Second-order low-pass Butterworth filter at 6 Hz and 50 Hz	STS and sit-to-walk; A chair without a backrest and armrest was used; the seat height was adjusted to the length of the lower leg. The starting position of sit-to-walk and STS was set with the knee flexed at 90° and the feet shoulder width apart. The sit-to-walk included walking 3 m. Each task was performed at a comfortable speed.	NR	HAT	Angular velocities	Maximal horizontal velocity of HAT was occurred later in a sit-to-walk motion than in STS; horizontal velocity of HAT was higher in sit-to-walk than in STS at seat-off; there was no difference between maximal vertical HAT during STS and sit-to-walk.

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Table 2 (continued)

Study	Characteristics of motion analysis system and markers/sensors' position		Measurement frequency, Hz		Processing	Task and test procedure	Number of trials	Spinal segment modeling	Outcome measures	Conclusion
	Participants' characteristics	sensors' position	Hz	Analysis software						
Shum et al <sup>1</sup> (2005), United Kingdom <sup>a</sup>	Sixty subacute LBP participants and 20 healthy participants (gender: unknown); age: 40.37 (9.47) y, height: 180.53 (4.40) cm, and body mass: 69.94 (26.55) kg	3Space Fastrak; 4 sensors were placed over L1 spinous process, sacrum, and lateral aspect of Rt and Lt thighs	100	NR	NR	STS and its reverse; A stool with neither armrest nor backrest was adjusted to 110% of fibular apex-floor length, the arms hanging freely beside the body, and foot placement was not restrained. Participants were instructed to rise freely at their comfortable speed and then maintain erect posture for 3 s. Then, they were instructed to sit down.	A 3	L1 to sacrum: lumbar segment	Peak flexion, extension, mean angular velocity, the ratios of the total movements of the lumbar spine to the Rt hip and Lt hip, coordination in LBP	Limited lumbar spine mobility and angular velocity in LBP participants; reduced ratio of movements and lumbar spine-hip and Lt hip, coordination in LBP participants
Tully et al <sup>40</sup> (2005), Australia <sup>a</sup>	Forty-seven healthy physiotherapy students (20 males and 27 females); age: 20.1 (2.8) y and BMI: 20.7 (2.3) kg/m <sup>2</sup>	2-D Peak Motus Motion Analysis System (PEAK Performance Technologies Inc, Englewood, CO); 10 reflective markers were placed over T1, T3, T11, L1, Rt PSIS, Rt ASIS, 2/3 Rt thigh, Rt SC, Rt LTC, and Rt LM	NR	KaleidaGraph (version 3.8, Synergy Software, Reading, PA) and Microsoft Excel program	Low-pass Butterworth filter at 6 Hz	STS; Participants with bare feet were asked to stand up at preferred speed from a chair set at 100% knee-floor height, arms folded across the chest.	NR	T1–T3 to T11–L1: thoracic segment, T11–L1 to the line joining the PSIS–buttocks LO ASIS: lumbar segment	Peak flexion and extension, ROM, excursion (end cycle, Prior to minus start angle), and buttocks LO ASIS: lumbar timing	Buttocks LO was occurred at 41.2% of STS cycle. Prior to LO, lumbar flexion was occurred; at LO, the lumbar spine flexed and the thoracic spine extended; following LO; the lumbar spine extended and the thoracic spine flexed.

Abbreviations: AC, acromion; AP, anteroposterior; ASIS, anterior superior iliac spine; BMI, body mass index; CNLBP, chronic nonspecific low back pain; CLBP, chronic low back pain; 2-D, 2-dimensional; GT, greater trochanter; HAT, head–arm–trunk; ICC, intraclass correlation coefficient; IJ, deepest point of incisura jugularis; LA, lateral ankle; LBP, low back pain; LK, lateral knee; LM, lateral malleolus; LO, lift-off; Lt, left; LTC, lateral tibial condyle; MA, medial ankle; MAI, midpoint between the inferior angles of most caudal points of the 2 scapulae; MK, medial knee; MTP, metatarsophalangeal; NR, not reported; PSIS, posterior superior iliac spine; PX, xiphoid process; ROM, range of motion; Rt, right; SC, supracondylar thigh; STS, sit-to-stand.

<sup>a</sup>High quality article according to quality assessment results.

acceleration to avoid exacerbation of pain caused by muscle contraction and high levels of acceleration.<sup>1</sup> Shum et al findings were consistent with the result of a previous study, in which LBP had more significant effects on trunk velocities than trunk mobility.<sup>59</sup> However, Crosbie et al<sup>60</sup> reported altered kinematics in recurrent patients with LBP who were in a pain-free period at the time of experiment. The main reason could be related to changes of spinal motor behavior due to reorganization of motor task planning.<sup>61–63</sup> Previous studies have recommended differentiating the lower and upper lumbar spine regions and evaluating thoracic kinematics for the assessment of STS.<sup>24,47,60</sup> They believe that analyzing STS using a multisegment lumbar model assists in achieving a better understanding of spine kinematics compared with a single-segment lumbar model. Christe et al<sup>50</sup> indicated that, in patients with nonspecific CLBP, flexion ROM reduction occurred principally at the upper lumbar segment. As STS movement is often described as a painful maneuver by patients with LBP,<sup>1,16,64</sup> Christe et al<sup>50</sup> suggested that pain is related to the rapid changes from a flexion to an extension posture required by this task. Moreover, interjoint discoordination is present in patients with LBP compared with asymptomatic individuals.<sup>1,51</sup> Shum et al<sup>1</sup> used relative phase angle, and Shafizadeh<sup>51</sup> used decomposition index to assess lumbar–hip coordination. Phase angle is defined as the inverse tangent of angular velocity/angular displacement.<sup>1,65</sup> The relative phase angle between 2 joints is quantified by subtracting the phase angle of one from the other.<sup>1,65</sup> In addition, decomposition index for the lumbar–hip joint pair is defined when one joint is moving while the other joint is paused.<sup>51</sup> The results of 2 studies showed that lumbar–hip coordination is more separated in time and more variable in LBP people.<sup>1,51</sup> Reduction in the angular velocity of both lumbar and hip joints during STS and its reverse,<sup>1,59</sup> and difficulty in transferring the muscle force from the pelvis to the lower limbs,<sup>51,66</sup> can cause lumbar–hip discoordination. A point worth mentioning here is that the reliability of marker/sensor placement techniques for evaluating lumbar–hip coordination using these methods has not been well established in the literature, and more studies are warranted to investigate the reliability of various marker/sensor placement techniques for assessing lumbar–hip coordination using the abovementioned methods.

In studying STS, it is essential to know that Parkinson et al<sup>47</sup> demonstrated that there were significant between-gender differences when the lumbar spine was modeled as 2 segments: the lower lumbar and upper lumbar regions. In the present study, healthy female participants showed greater peak flexion ROM in the upper lumbar segment, whereas peak flexion ROM in healthy male participants was greater in the lower segment.<sup>47</sup> Furthermore, no between-gender differences were found when the lumbar spine was modeled as a single region.<sup>47</sup>

Hughes et al<sup>3</sup> described 3 strategies (momentum transfer, stabilization, and hybrid) used in humans STS activity that generate different movements. They reported that younger individuals tend to use the momentum transfer strategy that utilizes the momentum to lift up their body.<sup>52</sup> However, the elderly persons tend to use the stabilization strategy, in which they carry their center of mass first on their feet and then they move upward.<sup>52</sup> The hybrid strategy is in the middle between momentum transfer and stabilization strategies.<sup>52</sup> Yang et al<sup>52</sup> found that the lumbar spine had larger ROM when using a stabilization strategy. They also showed that the subjects need to flex their body more to move their center of mass forward when using a stabilization strategy.<sup>52</sup> The present study showed that 4 muscle synergies could generate STS motion, and

the study subjects adaptively changed the start time of a certain synergy to achieve different strategies.<sup>52</sup>

One study suggested that low seat height can increase L5–S1 joint ROM during STS.<sup>49</sup> Besides, it has been reported that low seat height can result in an increase in the amount of paraspinal muscles activation and in the L5–S1 peak net joint torque compared with high and neutral seat heights.<sup>49</sup> Hence, seat height modification in patients with LBP may greatly improve their quality of daily activities. Kuo et al<sup>67</sup> mentioned that a high seat position is less demanding for the lumbar spine.

Slaboda et al<sup>42</sup> showed that adult subjects, when seated in a moving visual environment, compensated for the constantly changing environment by decreasing the head and trunk angular velocities, as well as head and trunk center of mass velocities, from the initiation of STS motion to the standing position. During STS, the center of mass is displaced from a seated position to a standing position through the coordinated motion of the upper and lower body segments.<sup>68</sup> If adults altered the displacement in response to the visual field motion, STS kinematics would be changed, which could potentially cause instability if the center of mass moved away from the lower limbs. In decreasing velocity, adults moved their bodies the same distance in the sagittal plane, but at a slower speed. This strategy may be used by adults to control the location of the center of mass when they realize that the visual environment is moving separately from their own movement.<sup>42</sup> In another study, Kouta et al<sup>41</sup> compared 2 common activities (STS vs sit-to-walk) among healthy young adults. The results of their study showed that the center of gravity moved higher in STS than sit to walk and moved further forward in sit-to-walk task.<sup>41</sup> Finally, Kouta et al<sup>41</sup> concluded that the forward translation of the center of gravity during sit-to-walk activity requires more advanced motor control ability.

Intravariability and intervariability is inherent in all biological systems<sup>69</sup> and is, therefore, an important parameter to measure.<sup>18</sup> The majority of the included studies recorded between 3 and 15 trials, and linear statistical methods such as SD, intraclass correlations, and coefficients of variation were utilized to analyze the variance of ROM values between trials and individuals. Several issues can affect reliability, including accurate identification of anatomical landmarks, familiarity of subjects with testing procedures, firm placement of markers or sensors over the skin, number of trial repetitions, sample size, experience of examiner(s), calibration of measurement system, and the region of the spine and type of ROM being examined.<sup>70</sup> All these parameters should be considered during the assessment of STS using a motion analysis system.

## Study Limitations and Future Research Recommendation

The present study can be criticized by some limitations. First, only the studies published in peer-review journals were reviewed in this study, and as in other reviews, a publication bias may have occurred. Second, a language bias is possible as only those studies that were available as full text in English were included. Third, only the kinematics of healthy adults and patients with LBP were assessed in this review. Further reviews can evaluate the kinematics of elderly people or patients with a specific pathology (such as stroke, Parkinson's disease, etc) during STS. Moreover, future original researches can investigate the effects of physiotherapy treatment programs on the kinematics of the spine in patients with LBP.<sup>1,65</sup>

## Conclusion

From the 16 studies included in this review, 10 studies were deemed high quality. Six studies had lesser quality based on the quality assessment results; therefore, a definitive conclusion cannot be drawn from the results of those studies. However, the results of this review demonstrated that there are differences in the kinematics of the spine between healthy people and patients with LBP. Several studies recommended that in order to develop a better understanding of spine kinematics, the trunk should be analyzed as a multisegment. One study revealed that high seat height reduces loads on the lumbar spine and, therefore, improves daily activities performance of patients with LBP. Further studies in healthy and subclinical populations with LBP are necessary to develop a better understanding of spine kinematics during STS.

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